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BISPECIFIC ANTI-ERB-B ANTIBODIES AND THEIR USE IN TUMOR THERAPY**FIELD OF THE INVENTION**

The invention relates to novel bispecific antibodies and their use in tumor therapy. The
5 novel antibodies have the ability to bind to ErbB receptors, especially ErbB1 receptors,
which are overexpressed on many cancer tissues. Since the different specificities of the
antigen-binding sites are directed to different epitopes within the binding domain of same
or different ErbB receptors, these antibodies are more effective with respect to inhibition
and down-regulation of the ErbB receptor and the corresponding signaling cascade. The
10 invention relates also to pharmaceutical compositions comprising said bispecific
antibodies or fragments thereof and additional pharmaceutically effective agents such as
monospecific antibodies, immunoconjugates and / or cytotoxic agents.

BACKGROUND OF THE INVENTION

15 Biological molecules, such as monoclonal antibodies (MAbs) or other proteins /
polypeptides, as well as small chemical compounds directed against various receptors and
other antigens on the surface of tumor cells are known to be suitable for tumor therapy for
more than twenty years. With respect to the antibody approach, most of these MAbs are
chimerized or humanized to improve tolerability with the human immune system. MAbs
20 or above-mentioned chemical entities specifically bind to their target structures on tumor
cells and in most cases also on normal tissues and can cause different effects that
dependent on their epitope specificity and/or functional characteristics of the particular
antigen. MAbs to orphan receptors or other non-functional cell surface molecules as well
as MAbs against structures outside the ligand-binding site of functionally active receptors
25 (e.g. growth factor receptors with kinase activity) would be expected to induce primarily
immune effector functions against the target cell (antibody-dependent cell-mediated
cytotoxicity (ADCC), complement-dependent cytotoxicity (CDC)). Additionally,
depending on the properties of antigen and MAb, binding of the antibody can result in
cross-linking of the receptors. Consequent internalization of the receptor-antibody
30 complexes may result in a prolonged down-modulation of the receptor density on the cell
surface.

MAbs which bind to an epitope within the ligand-binding site or in its direct
neighborhood compete for binding of natural ligands to their receptor and thus reduce or
completely inhibit ligand binding and can displace already bound ligands from their

receptors. This receptor blockade inhibits ligand-dependent receptor activation and downstream signaling. For example, blockade of ErbB receptors, such as the epidermal growth factor receptor (EGFR), by monoclonal antibodies results in various cellular effects including inhibition of DNA synthesis and proliferation, induction of cell cycle arrest and apoptosis as well as antimetastatic and antiangiogenic effects.

ErbB receptors are typical receptor tyrosine kinases that were implicated in cancer in the 1980s. Tyrosine kinases are a class of enzymes that catalyze the transfer of the terminal phosphate of adenosine triphosphate to tyrosine residues in protein substrates. Tyrosine kinases are believed, by way of substrate phosphorylation, to play critical roles in signal transduction for a number of cell functions. Though the exact mechanisms of signal transduction is still unclear, tyrosine kinases have been shown to be important contributing factors in cell proliferation, carcinogenesis and cell differentiation. Tyrosine kinases can be categorized as receptor type or non-receptor type. Both receptor-type and non-receptor type tyrosine kinases are implicated in cellular signaling pathways leading to numerous pathogenic conditions, including cancer, psoriasis and hyperimmune responses. Many tyrosine kinases are involved in cell growth as well as in angiogenesis. The non-receptor type of tyrosine kinases is also comprised of numerous subfamilies, including Src, Frk, Btk, Csk, Abl, Zap70, Fes/Fps, Fak, Jak, Ack, and LIMK. Each of these subfamilies is further sub-divided into varying receptors. For example, the Src subfamily is one of the largest and includes Src, Yes, Fyn, Lyn, Lck, Blk, Hck, Fgr, and Yrk. The Src subfamily of enzymes has been linked to oncogenesis. For a more detailed discussion of the non-receptor type of tyrosine kinases, see Bolen *Oncogene*, 8:2025-2031 (1993).

Receptor type tyrosine kinases have an extracellular, a transmembrane, and an intracellular portion, while non-receptor type tyrosine kinases are wholly intracellular. Receptor-linked tyrosine kinases are transmembrane proteins that contain an extracellular ligand binding domain, a transmembrane sequence, and a cytoplasmic tyrosine kinase domain. The receptor-type tyrosine kinases are comprised of a large number of transmembrane receptors with diverse biological activity.

Different subfamilies of receptor-type tyrosine kinases have been identified. Implicated tyrosine kinases include fibroblast growth factor (FGF) receptors, epidermal growth factor (EGF) receptors of the ErbB major class family, and platelet-derived growth factor

(PDGF) receptors. Also implicated are nerve growth Factor (NGF) receptors, brain-derived neurotrophic Factor (BDNF) receptors, and neurotrophin-3 (NT-3) receptors, and neurotrophin-4 (NT-4) receptors.

- 5 One receptor type tyrosine kinase subfamily, designated as HER or ErbB subfamily, is comprised of EGFR (ErbB1), HER2 (ErbB2 or p185neu), HER3 (ErbB3), and HER4 (ErbB4 or tyro2). Ligands of this subfamily of receptors include epithelial growth factor (EGF), TGF- α , amphiregulin, HB-EGF, betacellulin, heregulin and neuregulins. The PDGF subfamily includes the FLK family which is comprised of the kinase
- 10 insert domain receptor (KDR).

EGFR, encoded by the *erbB1* gene, has been causally implicated in human malignancy. In particular, increased expression of EGFR has been observed in breast, bladder, lung, head, neck and stomach cancer as well as glioblastomas. Increased EGFR receptor

15 expression is often associated with increased production of the EGFR ligand, transforming growth factor alpha (TGF- α), by the same tumor cells resulting in receptor activation by an autocrine stimulatory pathway (Baselga and Mendelsohn, *Pharmac. Ther.* 64:127-154 (1994)).

The EGF receptor is a transmembrane glycoprotein which has a molecular weight of

20 170.000, and is found on many epithelial cell types. It is activated by at least three ligands, EGF, TGF- α (transforming growth factor alpha) and amphiregulin. Both epidermal growth factor (EGF) and transforming growth factor-alpha (TGF- α) have been demonstrated to bind to EGF receptor and to lead to cellular proliferation and tumor growth. These growth factors do not bind to HER2 (Ulrich and Schlesinger, 1990, *Cell*

25 61, 203). In contrary to several families of growth factors, which induce receptor dimerization by virtue of their dimeric nature (e.g. PDGF) monomeric growth factors, such as EGF, contain two binding sites for their receptors and, therefore, can cross-link two neighboring EGF receptors (Lemmon et al., 1997, *EMBO J.* 16, 281). Receptor dimerization is essential for stimulating of the intrinsic catalytic activity and for the self-

30 phosphorylation of growth factor receptors on tyrosine residues. The latter serve as docking sites for various adaptor proteins or enzymes, which simultaneously initiate many signaling cascades. In higher eukaryotes, the simple linear pathway has evolved into a richly interactive, multi-layered network in which combinatorial expression and

activation of components permits context-specific biological responses throughout development. The ErbB network might integrate not only its own inputs but also heterologous signals, including hormones, lymphokines, neurotransmitters and stress inducers.

- 5 It should be remarked that receptor protein tyrosine kinases (PTKs) are able to undergo both homo- and heterodimerization, wherein homodimeric receptor combinations are less mitogenic and transforming (no or weak initiation of signaling) than the corresponding heterodimeric combinations. Heterodimers containing ErbB2 are the most potent complexes (see review articles by Yarden and Sliwkowski, 2001, *Nature Reviews*,
10 *Molecular cell Biology*, volume 2, 127 – 137; Tzahar and Yarden, 1998, *BBA* 1377, M25-M37).

- It has been demonstrated that anti-EGF receptor antibodies while blocking EGF and TGF-
a binding to the receptor appear to inhibit tumor cell proliferation. In view of these
15 findings, a number of murine and rat monoclonal antibodies against EGF receptor have been developed and tested for their ability inhibit the growth of tumor cells in vitro and in vivo (Modjtahedi and Dean, 1994, *J. Oncology* 4, 277). Humanized monoclonal antibody 425 (h MAb 425, US 5,558,864; EP 0531 472) and chimeric monoclonal antibody 225 (c MAb 225, US 4,943,533 and EP 0359 282), both directed to the EGF receptor, have
20 shown their efficacy in clinical trials. The C225 antibody (Cetuximab) was demonstrated to inhibit EGF-mediated tumor cell growth in vitro and inhibit human tumor formation in vivo in nude mice. The antibody, moreover, appeared to act, above all, in synergy with certain chemotherapeutic agents (i.e., doxorubicin, adriamycin, taxol, and cisplatin) to eradicate human tumors in vivo in xenograft mouse models. Ye et al. (1999, *Oncogene*
25 18, 731) have reported that human ovarian cancer cells can be treated successfully with a combination of both chimeric MAb 225 and humanized MAb 4D5 which is directed to the HER2 receptor.

- The second member of the ErbB family, HER2 (ErbB2 or p185*neu*), was originally
30 identified as the product of the transforming gene from neuroblastomas of chemically treated rats. The activated form of the neu proto-oncogene results from a point mutation (valine to glutamic acid) in the transmembrane region of the encoded protein. Amplification of the human homologue of *neu* is observed in breast and ovarian cancers and correlates with a poor prognosis (Slamon *et al.*, *Science*, 235: 177-182

(1987); Slamon *et al.*, *Science*, 244:707-712 (1989); US 4,968,603). ErbB2 (HER2) has a molecular weight of about 185.000, with considerable homology to the EGF receptor (HER1), although a specific ligand for HER2 has not yet been clearly identified so far. The antibody 4D5 directed to the HER2 receptor, was further found to sensitize ErbB2-overexpressing breast tumor cell lines to the cytotoxic effects of TNF α (US 5,677,171). A recombinant humanized version of the murine anti-ErbB2 antibody 4D5 (huMAb4D5-8, rhuMAb HER2 or HERCEPTIN®; US 5,821,337) is clinically active in patients with ErbB2-overexpressing metastatic breast cancers that have received extensive prior anti-cancer therapy (Baselga *et al.*, *J. Clin. Oncol.* 14:737-744 (1996)). HERCEPTIN® received marketing approval in 1998 for the treatment of patients with metastatic breast cancer whose tumors overexpress the ErbB2 protein.

Besides anti-ErbB antibodies there are numerous small chemical molecules which are known to be potent inhibitors of ErbB receptor molecules blocking the binding site of the natural ligands (see detailed description), or blocking the tyrosine residues of the binding site of the receptor kinase, thus preventing phosphorylation and further cascade signaling. One representative showing high efficacy in clinical trials is Iressa™ (ZD-1839) which can be applied for NSCLC indication (non-small cell lung cancer).

Although there are already some promising drugs and methods of treatment tumors under development and in the market, there is a continuous need for further agents and pharmaceutical compositions and combinations with improved properties and enhanced efficacy.

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SUMMARY OF THE INVENTION

The invention is based on the observation of the inventors, that certain receptor tyrosine kinases such as ErbB receptor molecules which are overexpressed on diseased cell surfaces, e.g. tumor cells, have specific epitope sites within the natural ligand binding domain to which simultaneously different antibodies or, generally spoken, different specificities, may be bound without or only negligible mutual hindrance. Evidently, these antibodies or specificities possess binding epitopes which are with respect to their three-dimensional configuration relatively small, as compared with the total size of the binding domain of the receptor molecule. They induce an increased down-modulation activity of

pathway signaling, preferably an increased blocking of the ErbB receptor and, thus, of the complete signaling cascade.

The present invention describes for the first time the new concept in tumor therapy to administer to an individual a bispecific antibody or a functionally effective fragment thereof that blocks or inhibits an ErbB receptor, preferably the EGF receptor (EGFR), by binding of the first specific antigen-binding site of said bispecific antibody to a first epitope and the second specific antigen-binding site to a second different epitope of the same or different receptor.

It could be found that such a bispecific antibody can bind simultaneously by its two different antigen-binding sites to different epitopes within the natural ligand(s) binding domain either of the same receptor molecule (e.g. EGFR or Her-2) or different receptor molecules (e.g. EGFR and Her-2) without significant mutual hindrance of the different antigen-binding sites of the antibody, thus enabling a higher antibody density on the receptor and affecting (by a less ability to bind natural (agonistic) ligands such as EGF or TGF α) a much stronger inhibition of the signaling cascade of the corresponding receptor molecules as monomeric or dimeric units. This should lead to a stronger inhibition of tumor growth and / or increased apoptosis of solid tumors or tumor metastases. Preferred antibodies are especially anti-EGFR and anti-Her2 antibodies as specified above and below, and fragments thereof, preferably bispecific F(ab')₂ fragments for reasons of their smaller size. In a preferred embodiment of this invention a bispecific antibody (fragment) consisting of a first antigen-binding site deriving from MAb 425 in a humanized, chimeric or murine version and a second antigen-binding site deriving from MAb 225 in a humanized, chimeric or murine version is disclosed (BAb <425, 225>, F(ab' <425>, ab' <225>)). In another embodiment of this invention a bispecific antibody (fragment) consisting of a first antigen-binding site deriving from MAb 425 in a humanized, chimeric or murine version and a second antigen-binding site deriving from MAb 4D5 in a humanized, chimeric or murine version is disclosed (BAb <425, 4D5>, F(ab' <425>, ab' <4D5>)) is disclosed. In a further embodiment of this invention a bispecific antibody (fragment) consisting of a first antigen-binding site deriving from MAb 225 in a humanized, chimeric or murine version and a second antigen-binding site deriving from MAb 4D5 in a humanized, chimeric or murine version is disclosed (BAb <225, 4D5>, F(ab' <425>, ab' <4D5>)) is disclosed. In above-said embodiments humanized MAb 425, chimeric MAb225 (CETUXIMAB®) and humanized 4D5 (HERCEPTIN®) are preferred as source antibodies. In principle the invention includes also heteroantibodies or fragments

thereof. Such a synthetically manufactured heteroantibody may even consist of three different antigen-binding site portions deriving from three different anti-EGFR antibodies or fragments thereof (e.g. <425, 225, 4D5>).

- 5 It was found that the bispecific antibodies according to this invention can affect enhanced cross-linking / dimerization of different or identical ErbB receptors, enhanced blocking / inhibition of ErbB receptors, and enhanced induction of modulation of ErbB receptor-specific pathway signaling as compared with the respective monospecific antibodies. Interestingly this cross-linking effect can be further enhanced by a mixture comprising a
- 10 bispecific antibody (fragment) as described and a monospecific anti-ErbB antibody (fragment), preferably having antigen-binding sites which are identical with said first or second antigen-binding sites of the bispecific antibody (fragment). In other words: a mixture of, for example, (i) MAb 425 or MAb 225 or MAb 4D5 and BAb <425, 225>, or (ii) MAb 425 or MAb 225 or MAb 4D5 and BAb <425, 4D5>, or (iii) MAb 425 or
- 15 MAb 225 or MAb 4D5 and BAb <4D5, 225> elicit an enhanced inhibition and down-regulation of ErbB receptors as MAbs or BAbs applied as single agent in the same concentration.

- Although above-described observations were made for ErbB receptors as target receptor
- 20 molecules only it should be pointed out that the scientific principle discovered by the inventors and stated out above and below might be also applicable for other biological receptors other than ErbB.

- Optionally, the composition according to this invention comprises further therapeutically
- 25 active compounds which may support and enhance the efficacy of above-said molecules. Such agents may cytotoxic agents and preferably antagonistic molecules, such as tyrosine kinase antagonists, other ErbB antagonists, hormone receptor antagonists, protein kinase antagonists or anti-angiogenic agents. Such molecules usable in the present invention are specified in more detail below.

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According to this invention the therapeutically active agents may also be provided by means of a pharmaceutical kit comprising a packages containing one or more of said antagonistic agents in single or separate containers. The therapy with this combinations may include optionally treatment with radiation. Principally, the administration can be

accompanied by radiation therapy, wherein radiation treatment can be done substantially concurrently or before or after the drug administration. The administration of the different agents of the combination therapy according to the invention can also be achieved substantially concurrently or sequentially. Tumors, bearing receptors on their cell surfaces
5 involved in the development of the blood vessels of the tumor, may be successfully treated by the combination therapy of this invention.

It is known that tumors elicit alternative routes for their development and growth. If one route is blocked they often have the capability to switch to another route by expressing
10 and using other receptors and signaling pathways. Therefore, the pharmaceutical combinations of the present invention may block several of such possible development strategies of the tumor and provide consequently various benefits. The combinations according to the present invention are useful in treating and preventing tumors, tumor-like and neoplasia disorders and tumor metastases, which develop and grow by activation of
15 their relevant hormone receptors which are present on the surface of the tumor cells. Preferably, the different combined agents of the present invention are administered in combination at a low dose, that is, at a dose lower than has been conventionally used in clinical situations. A benefit of lowering the dose of the compounds, compositions, agents and therapies of the present invention administered to an individual includes a decrease in
20 the incidence of adverse effects associated with higher dosages. For example, by the lowering the dosage of an agent described above and below, a reduction in the frequency and the severity of nausea and vomiting will result when compared to that observed at higher dosages. By lowering the incidence of adverse effects, an improvement in the quality of life of a cancer patient is contemplated. Further benefits of lowering the
25 incidence of adverse effects include an improvement in patient compliance, a reduction in the number of hospitalizations needed for the treatment of adverse effects, and a reduction in the administration of analgesic agents needed to treat pain associated with the adverse effects. Alternatively, the methods and combination of the present invention can also maximize the therapeutic effect at higher doses.

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The combinations mentioned above show an astonishing synergetic effect. In administering the combination of drugs real tumor shrinking and disintegration could be observed during clinical studies while no significant adverse drug reactions were detectable.

The invention generally refers to:

- A bispecific antibody, or a functionally effective fragment thereof, comprising a first antigen-binding site that binds to a first epitope of a first ErbB receptor and a second different antigen-binding site that binds to a second epitope of a second ErbB receptor.
- A corresponding bispecific antibody or fragment thereof, wherein said first and / or said second epitope is located within the binding domain of the natural ligand of said receptor(s).
- A corresponding bispecific antibody or fragment thereof affecting enhanced blocking and / or inhibition of ErbB receptor, and enhanced induction of down-regulation of ErbB receptor-specific pathway signaling as compared with the respective monospecific antibody.
- A corresponding bispecific antibody or fragment thereof affecting enhanced induction of crosslinking and / or dimerization of receptor molecules having the same or different specificity.
- A corresponding bispecific antibody or fragment thereof, wherein said first epitope of the first ErbB receptor is different from the second epitope of the second ErbB receptor.
- A bispecific antibody or fragment thereof of claim 5, wherein said first ErbB receptor is different from said second ErbB receptor.
- A corresponding bispecific antibody or fragment thereof, wherein said first and second ErbB receptors are identical.
- A corresponding bispecific antibody or fragment thereof, wherein said first ErbB receptor is EGF receptor (EGFR).
- A corresponding bispecific antibody or fragment thereof, wherein said second ErbB receptor is ErbB-2 (Her-2).
- A corresponding bispecific antibody or fragment thereof, wherein said first and second ErbB receptor is EGF receptor (EGFR).
- A corresponding bispecific antibody or fragment thereof, wherein said first antigen-binding site derives from humanized, chimeric or murine MAb 425.
- A corresponding bispecific antibody or fragment thereof, wherein said first antigen-binding site derives from humanized, chimeric or murine MAb 225.

- A corresponding bispecific antibody or fragment thereof, wherein said first antigen-binding site derives from humanized, chimeric or murine MAb 425, and said second antigen-binding site derives from humanized, chimeric or murine MAb 225, and each antigen-binding site binds to a different epitope within the binding domain of the natural ligand(s) of the same EGF receptor molecule.
- A corresponding bispecific antibody or fragment thereof, wherein said first ErbB receptor is EGF receptor (EGFR) and said second ErbB receptor is ErbB-2 (Her-2).
- A corresponding bispecific antibody or fragment thereof, wherein said first antigen-binding site derives from humanized, chimeric or murine MABs 425 or 225, and said second antigen-binding site derives from MAb 4D5 (Herceptin®).
- A corresponding bispecific antibody or fragment thereof, wherein the fragment is F(ab')₂.
- A pharmaceutical composition comprising a bispecific antibody or a functionally effective fragment thereof as specified in any of the above-mentioned claims and optionally a pharmaceutically acceptable carrier, diluent or excipient.
- A corresponding pharmaceutical composition further comprising a monospecific anti-ErbB antibody or a functionally effective fragment thereof.
- A corresponding pharmaceutical composition, wherein said monospecific anti-ErbB antibody or a functionally effective fragment thereof is selected from the group consisting of MAb 425, MAb 225, or MAb 4D5 (Herceptin®).
- A corresponding pharmaceutical composition, additionally comprising a cytotoxic agent.
- A corresponding pharmaceutical composition, wherein said cytotoxic agent is a chemotherapeutic agent.
- A corresponding pharmaceutical composition, wherein said chemotherapeutic agent is selected from any of the compounds of the group: cisplatin, doxorubicin, gemcitabine, docetaxel, paclitaxel, bleomycin.
- A corresponding pharmaceutical composition, wherein said cytotoxic agent is an ErbB receptor inhibitor, a tyrosine kinase inhibitor, a protein kinase A inhibitor, or an anti-angiogenic agent.
- A pharmaceutical kit comprising
 - (i) a first package comprising at least a bispecific antibody or a functionally

effective fragment thereof as specified above, and

(ii) a second package comprising at least a monospecific anti-ErbB antibody or a functionally effective fragment thereof.

- 5 • A corresponding pharmaceutical kit comprising a first package that comprises BAb <h425, c225> or its F(ab')₂ fragment, and a second package that comprises humanized MAb 425 (h425), chimeric MAb 225 (c225) or humanized MAb 4D5 or functionally effective fragments thereof.
- A corresponding pharmaceutical kit comprising additionally a third package comprising a further agent.
- 10 • A corresponding pharmaceutical kit, wherein said additional agent is a cytotoxic drug.
- A corresponding pharmaceutical kit, wherein said cytotoxic drug is selected from any of the compounds of the group: cisplatin, doxorubicin, gemcitabine, docetaxel, paclitaxel, bleomycin, ErbB receptor inhibitor, a tyrosine kinase
15 inhibitor, a protein kinase A inhibitor, or an anti-angiogenic agent.
- Use of a bispecific antibody or a pharmaceutical composition / kit as defined above, for the manufacture of a medicament for the treatment of tumors and tumor metastases that overexpress ErbB receptors.
- A method for treating tumors and tumor metastases that overexpress ErbB
20 receptors in an individual comprising administering to said individual a therapeutically effective amount of a bispecific antibody or functionally effective fragment thereof or a pharmaceutical composition / kit as defined above and in the claims.
- A method for enhancing down-regulation of ErbB receptor-specific pathway
25 signaling in tumors that overexpress ErbB receptors by administering to an individual a therapeutically effective amount of a bispecific antibody or functionally effective fragment thereof or a pharmaceutical composition / kit as defined above.
- A corresponding method, further comprising administering to the patient an
30 effective amount of a cytotoxic drug.
- A corresponding method, wherein said cytotoxic agent is a chemotherapeutic agent and is selected from any of the compounds of the group: cisplatin, doxorubicin, gemcitabine, docetaxel, paclitaxel, bleomycin.

- A corresponding method, wherein said cytotoxic drug is an ErbB receptor inhibitor, a tyrosine kinase inhibitor, a protein kinase A inhibitor, or an anti-angiogenic agent.

5 In a preferred embodiment the first ErbB receptor type to which one antigen binding site of the bispecific antibodies of the present invention binds is the ErbB1 receptor (EGFR). Thus, the invention relates in more detail to the following:

- 10 • A bispecific antibody, or a fragment thereof, having the capability to bind to different epitopes located on same or different ErbB receptor molecule types, said antibody comprising a first antigen-binding site that binds to an epitope of a first receptor type, which is ErbB1, and a second different antigen-binding site that binds to a different epitope of a second ErbB receptor molecule type.
- 15 • A bispecific antibody, wherein said second ErbB receptor molecule type is ErbB1 (EGFR).
- A bispecific antibody, wherein said second ErbB receptor molecule type is ErbB2 (Her-2).
- A bispecific antibody, wherein at least one of said epitopes is located within the receptor binding domain.
- 20 • A bispecific antibody, wherein said receptor binding domain is the binding domain of the natural ligand of said receptor.
- A bispecific antibody, wherein the first or second antigen binding site binds to an epitope within the binding domain of the natural ligand(s) of said ErbB receptor molecule types.
- 25 • A bispecific antibody, wherein the first and second antigen binding site binds to an epitope within the binding domain of the natural ligand(s) of said ErbB receptor molecule types.
- A bispecific antibody, wherein the antigen binding sites bind to different epitopes which are located on the same ErbB receptor molecule type.
- 30 • A bispecific antibody, wherein the antigen binding sites bind to different epitopes which are located on different ErbB receptor molecule types.
- A bispecific antibody, wherein the first and second antigen binding site binds each to a different epitope within the binding domain of the natural ligand of said ErbB

receptor molecule type, thus blocking and / or inhibiting the receptor, whereby blocking and / or inhibition of the ErbB receptor, and induction of down-regulation of ErbB receptor-specific pathway signaling is enhanced as compared with the respective monospecific antibody.

- 5 • A bispecific antibody, wherein induction of crosslinking and / or dimerization of different ErbB receptor molecules having the same or different specificity, is enhanced as compared with binding of the bispecific antibody to epitopes on the same ErbB receptor molecule type.
- A bispecific antibody, wherein said first antigen-binding site derives from
10 humanized, chimeric or murine MAb 425.
- A bispecific antibody according to any of the claims 1 – 11, wherein said first antigen-binding site derives from humanized, chimeric or murine MAb 225.
- A bispecific antibody designated as "BAb <h425, c225>", wherein said first antigen-binding site derives from humanized, chimeric or murine MAb 425, and said second
15 antigen-binding site derives from humanized, chimeric or murine MAb 225, and each antigen-binding site binds to a different epitope on the ErbB1 receptor (EGFR) molecule.
- A bispecific antibody, wherein said different epitopes are located within the binding domain of the natural ligand(s).
- 20 • A bispecific antibody, wherein the second antigen binding site binds to a ErbB2 receptor molecule (Her-2) or a VEGF receptor molecule.
- A bispecific antibody of claim 16, wherein said second antigen-binding site derives from MAb 4D5 (Herceptin®).
- A bispecific antibody fragment deriving from a bispecific antibody as defined above
25 and in any of the claims, wherein the fragment is F(ab')₂.
- A pharmaceutical composition comprising one or more of the bispecific antibodies or fragments thereof as specified above and in the claims, optionally together with a pharmaceutically acceptable carrier, diluent or excipient.
- A pharmaceutical composition, further comprising a monospecific anti-ErbB
30 antibody or a functionally effective fragment thereof.
- A pharmaceutical composition, wherein said monospecific anti-ErbB antibody or a functionally effective fragment thereof is selected from the group consisting of MAb 425, MAb 225, or MAb 4D5 (Herceptin®).

- A pharmaceutical composition, additionally comprising a cytotoxic agent.
- A pharmaceutical composition, wherein said cytotoxic agent is a chemotherapeutic agent.
- A pharmaceutical composition, wherein said chemotherapeutic agent is selected from
5 any of the compounds of the group: cisplatin, doxorubicin, gemcitabine, docetaxel, paclitaxel, bleomycin.
- A pharmaceutical composition, wherein said cytotoxic agent is an ErbB receptor inhibitor, a VEGF receptor inhibitor, a tyrosine kinase inhibitor, a protein kinase A inhibitor, an anti-angiogenic agent, an anti-hormonal agent, or a cytokine.
- 10 • An immunoconjugate comprising a bispecific antibody as defined above, fused directly or via a linker molecule via its C-terminus to a biologically effective protein, polypeptide or peptide, wherein preferably said protein or poly peptide is a cytokine.
- A pharmaceutical kit comprising (i) a first package comprising at least a bispecific antibody or an immunoconjugate, as specified above and in the claims, and (ii) a
15 second package comprising at least a monospecific anti-ErbB antibody or a functionally effective fragment thereof.
- A pharmaceutical kit comprising a first package that comprises bispecific antibody "BAb <h425, c225>" or its F(ab')₂ fragment or a immunoconjugate thereof, and a second package comprising humanized MAb 425 (h425), chimeric MAb 225 (c225)
20 or humanized MAb 4D5 or functionally effective antibody fragments or immunoconjugates thereof.
- A pharmaceutical kit comprising additionally a third package comprising a cytotoxic drug.
- A pharmaceutical kit, wherein said cytotoxic drug is selected from any of the
25 compounds of the group: cisplatin, doxorubicin, gemcitabine, docetaxel, paclitaxel, bleomycin, an ErbB receptor inhibitor, a VEGF receptor inhibitor, a tyrosine kinase inhibitor, a protein kinase A inhibitor, an anti-hormonal agent, or an anti-angiogenic agent.
- Use of a bispecific antibody or a pharmaceutical composition / kit as defined above,
30 for the manufacture of a medicament for the treatment of tumors and tumor metastases and related diseases that overexpress ErbB receptors.

DETAILED DESCRIPTION OF THE INVENTION

- This invention is based on the observation that two or more MAbs with specificities for different immunogenic structures can bind at the same time and without or with only insignificant hindrance to their epitopes, which may be located on the same receptor and even within the same receptor domain, e.g. within the ligand-binding domain. Therefore, bispecific antibodies with specificities for different epitopes of the same receptor can bind to both of their specific epitopes and thus form bivalent receptor-antibody complexes, which are not seen in most cases with monospecific MAbs on a single receptor.
- Alternatively, the antigen-binding sites of such bispecific antibodies can react with other identical receptors in near neighborhood and thus build complexes between these receptors. Additionally, bispecific antibodies directed against antigenic structures on different receptors of the same or different receptor families can be used to form complexes between these receptors.
- Application of one or more bispecific antibodies or combinations of mono- and bispecific antibodies directed against the same or different receptors can greatly improve the therapeutic efficacy compared to the efficacy of treatment with only one monospecific antibody:
- Each antigen-binding site of a bispecific antibody independently binds to its specific epitopes on the target receptor (e.g. EGFR).
 - Both antigen-binding sites of the bispecific antibody react with their specific epitopes, which can be located on the same receptor and possibly within the same receptor domain or on another receptor.
 - Bispecific antibodies independently can bind to two different epitopes on the same receptor. This increases the overall avidity of the bispecific antibody to a single receptor compared to the avidity of monospecific antibodies, which in most cases is restricted to monovalent binding to that receptor.
 - Due to the higher avidity to a single receptor, compared to a monospecific MAb, lower concentrations of the bispecific antibody are necessary to efficiently block the receptor.
 - Because bispecific antibodies are more efficient than monospecific MAbs for receptor blockade, they induce a more pronounced inhibition of receptor activation and downstream signaling.

- Similarly, one or more bispecific antibodies or mixtures of mono- and bispecific antibodies with specificities for different epitopes within or near the ligand-binding domain increase the efficacy of the receptor blockade.
- 5 • Because receptor blockade by combinations of two or more mono- and/or bispecific antibodies against the same receptor domain is more effective than receptor blockade by only one single mono- or bispecific antibody, a more effective inhibition of ligand-binding is attained, which results in a more effective inactivation of the receptor.
- 10 • This more efficient receptor inactivation results in a more effective inhibition of downstream receptor signaling and consequently in an increased impact on ligand-dependent cell functions.
- Due to the more efficient receptor blockade the dosage (or concentration) of each of the applied mono- and/or bispecific antibodies can be reduced without loss of efficacy. This can be of great interest when therapeutic antibodies are applied,
15 which show dose-limiting toxicities or side effects already below the optimal therapeutic dose.
- Bispecific antibodies as well as monospecific antibodies that bind to different receptors on the same cell will first form dimeric receptor-antibody complexes. However, due to their different antigenic specificity, bispecific antibodies can
20 form receptor-antibody complexes, which are not limited to dimers of identical receptors. Thus, receptor aggregates formed by bispecific antibodies can contain large, theoretically unlimited numbers of receptors.
- These large receptor-antibody complexes improve internalization of the receptors and thus may be more efficient for removal of receptors from the cell surface and
25 consequent down-modulation of receptor-dependent cellular functions.
- Formation of large receptor-antibody complexes can further be enhanced by combinations of two or more mono- and/or bispecific antibodies and thus can further enhance internalization of the receptors and down-modulation of receptor-dependent cellular functions.
- 30 • Use of bispecific antibodies and combinations of two or more mono- and/or bispecific antibodies against the same or different receptors can be used for treatment of tumors carrying appropriate receptors. EGFR positive tumors are a typical example, however application of the therapeutic principle described in this

invention is not limited to this indication. Thus, a wide variety of tumors carrying other receptors, receptor families or other antigenic structures can be treated using the same principle.

- 5 • The treatment with bispecific antibodies or the combined treatment with two or more mono- and/or bispecific antibodies directed against different antigens on the same or different receptors is also applicable as combination therapy together with chemotherapeutic drugs and/or irradiation.
- 10 • The treatment with bispecific antibodies or the combined treatment with two or more mono- and/or bispecific antibodies directed against different antigens on the same or different receptors can as well be used in combination with other therapeutic principles including but not limited to treatment with hormone antagonists or hormone agonists, angiogenesis inhibitors and other treatments.

15 The principle of combined treatment with bispecific antibodies or combinations of mono- and bispecific antibodies with specificities to different antigen structures on the same or different receptors is described here exemplarily for treatment of EGFR positive tumors. However, this principle is not limited to the EGFR and can be adapted for use with any other target antigen.

20 If not otherwise pointed out the terms and phrases used in this invention have the meanings and definitions as given below. Moreover, these definitions and meanings describe the invention in more detail, preferred embodiments included.

25 A "*receptor*" or "*receptor molecule*" is a soluble or membrane bound / associated protein or glycoprotein comprising one or more domains to which a ligand binds to form a receptor-ligand complex. By binding the ligand, which may be an agonist or an antagonist the receptor is activated or inactivated and may initiate or block pathway signaling.

30 The term "*receptor molecule type*" or "*ErbB (ErbB1) receptor molecule type*" means a specific receptor type such as ErbB1, ErbB2, etc. but not a specific single molecule of this receptor type. In other word: a bispecific antibody according to the invention can bind by its first antigen-binding site to a first epitope of an individual ErbB1 receptor molecule, whereas the second antigen binding site of this antibody binds to a second

different epitope of the same individual ErbB1 receptor molecule. It is also possible that the second antigen binding site of this antibody binds to a second different epitope of another individual receptor molecule of the same type (ErbB1). Furthermore it is possible that the second antigen binding site of this antibody binds to a second different epitope of another individual receptor molecule of a different ErbB receptor molecule type (e.g. ErbB2).

By "*ligand*" or "*receptor ligand*" is meant a natural or synthetic compound which binds a receptor molecule to form a receptor-ligand complex. The term ligand includes agonists, antagonists, and compounds with partial agonist/antagonist action.

An "*agonist*" or "*receptor agonist*" is a natural or synthetic compound which binds the receptor to form a receptor-agonist complex by activating said receptor and receptor-agonist complex, respectively, initiating a pathway signaling and further biological processes.

By "*antagonist*" or "*receptor antagonist*" is meant a natural or synthetic compound that has a biological effect opposite to that of an agonist. An antagonist binds the receptor and blocks the action of a receptor agonist by competing with the agonist for receptor. An antagonist is defined by its ability to block the actions of an agonist. A receptor antagonist may be also an antibody or an immunotherapeutically effective fragment thereof. Preferred antagonists according to the present invention are cited and discussed below.

An "*ErbB receptor*" is a receptor protein tyrosine kinase which belongs, as already specified above, to the ErbB receptor family and includes EGFR (ErbB1), ErbB2, ErbB3 and ErbB4 receptors and other members of this family to be identified in the future. The ErbB receptor will generally comprise an extracellular domain, which may bind an ErbB ligand; a lipophilic transmembrane domain; a conserved intracellular tyrosine kinase domain; and a carboxyl-terminal signaling domain harboring several tyrosine residues which can be phosphorylated. The ErbB receptor may be a "native sequence" ErbB receptor or an "amino acid sequence variant" thereof. Preferably the ErbB receptor is native sequence human ErbB receptor. ErbB1 refers to the gene encoding the EGFR protein product. Mostly preferred is the EGF receptor (EGFR, HER1). The expressions "ErbB1" and "HER1" and "EGFR" are used interchangeably herein and refer to human

HER1 protein. The expressions "ErbB2" and "HER2" are used interchangeably herein and refer to human HER2 protein. ErbB1 receptors (EGFR) are preferred according to this invention

- 5 *"ErbB ligand"* is a polypeptide which binds to and/or activates an ErbB receptor. ErbB ligands which bind EGFR include, for example, EGF, TGF- α , amphiregulin, betacellulin, HB-EGF and epiregulin, preferably EGF and TGF- α .

- "ErbB receptor binding domain"* is in the context of this invention the local region
10 (binding sequence / loop / pocket) of the ErbB receptor to which a natural ligand or an antagonistic or agonistic drug binds. This region may comprise not only one specific binding site or epitope but two or more epitopes and binding sites, respectively. One specific binding epitope within the domain binds to one kind of antagonistic or agonistic drug or ligand. Nevertheless it is deemed, that the binding of different agents to different
15 epitopes within or nearly adjacent the binding domain of the same receptor type generally causes by inhibition or activation a distinct and unique signaling pathway that is typical for said receptor. Moreover, it should be pointed out that the phrase *"within the binding domain"* used in this description and claims includes also locations in close vicinity of the real binding domain of the respective natural ligand(s).

20

"ErbB binding epitope or binding site" means a conformation and / or configuration of amino acids within or in close vicinity of the binding domain of an ErbB receptor to which ligands or receptor antagonists / agonists bind.

- 25 *"Same ErbB / ErbB1 receptor molecule"* means not necessarily the identical receptor molecule, but includes also another receptor molecule of the same type. Preferably, the identical receptor molecule is meant.

- The term *"ErbB receptor antagonist / inhibitor"* refers to a biologically effective
30 molecule, which binds and blocks or inhibits the ErbB receptor. Thus, by blocking the receptor the antagonist prevents binding of the ErbB ligand (agonist) and activation of the agonist/ligand receptor complex. ErbB antagonists may be directed to HER1 (ErbB1, EGFR), HER2 (ErbB2) and ErbB3 and ErbB4. Preferred antagonists of the invention are directed to the EGF receptor (EGFR, HER1). The ErbB receptor antagonist may be an

antibody or an immunotherapeutically effective fragment thereof or non-immunobiological molecules, such as a peptide, polypeptide protein. Chemical molecules are also included, however, anti-EGFR antibodies and anti-HER2 antibodies are the preferred antagonists according to the invention.

- 5 Preferred antibodies of the invention are anti-Her1 and anti-Her2 antibodies, more preferably anti-Her1 antibodies. Preferred anti-Her1 antibodies are MAb 425, preferably humanized MAb 425 (hMAb 425, US 5,558,864; EP 0531 472) and chimeric MAb 225 (CETUXIMAB®). Most preferred is monoclonal antibody h425, which has shown in mono-drug therapy high efficacy combined with reduced adverse and side effects. Most
10 preferred anti-HER2 antibody is HERCEPTIN® commercialized by Genentech/Roche. Efficacious EGF receptor antagonists according to the invention may be also natural or synthetic chemical compounds. Some examples of preferred molecules of this category include organic compounds, organometallic compounds, salts of organic and organometallic compounds. Examples for chemical HER2 receptor antagonists are: styryl
15 substituted heteroaryl compounds (US 5,656,655); bis mono and/or bicyclic aryl heteroaryl, carbocyclic, and heterocarbocyclic compounds (US 5,646,153); tricyclic pyrimidine compounds (US 5,679,683); quinazoline derivatives having receptor tyrosine kinase inhibitory activity (US 5,616,582); heteroarylethenediyl or heteroaryl-ethenediylaryl compounds (US 5,196,446); a compound designated as 6-(2,6-
20 dichlorophenyl)-2-(4-(2-diethyl-aminoethoxy) phenylamino)-8-methyl-8H-pyrido(2,3)-5-pyrimidin-7-one (Panek, et al., 1997, J. Pharmacol. Exp. Therap. 283,1433) inhibiting EGFR, PDGFR, and FGFR families of receptors.

- The term "*tyrosine kinase antagonist/inhibitor*" refers according to this invention to
25 natural or synthetic agents that are enabled to inhibit or block tyrosine kinases, receptor tyrosine kinases included. Thus, the term includes per se ErbB receptor antagonists / inhibitors as defined above. With exception of the anti-ErbB receptor antibodies mentioned above and below, more preferable tyrosine kinase antagonist agents under this definition are chemical compounds which have shown efficacy in mono- drug therapy for
30 breast and prostate cancer. Suitable indolocarbazole-type tyrosine kinase inhibitors can be obtained using information found in documents such as US patents 5,516,771; 5,654,427; 5,461,146; 5,650,407. US patents 5,475,110; 5,591,855; 5,594,009 and WO 96/11933 disclose pyrrolocarbazole-type tyrosine kinase inhibitors and prostate cancer. One of the most promising anti-cancer agents in this context is gefitinib (IRESSA®, Astra Zeneca),

which is reported to possess outstanding therapeutic efficacy and excellent tolerability in patients with non-small cell lung cancer (NSCLC) as well as advanced head and neck cancer.

Preferably, the dosage of the chemical tyrosine kinase inhibitors as defined above is from 1 pg/kg to 1 g/kg of body weight per day. More preferably, the dosage of tyrosine kinase inhibitors is from 0.01 mg/kg to 100 mg/kg of body weight per day.

The biological molecules according to this invention are preferably antibodies or fragments thereof or any variations of antibodies such as immunoconjugates.

10

In this context, the term "*antibody*" or "*immunoglobulin*" herein is used in the broadest sense and specifically covers intact monoclonal antibodies, polyclonal antibodies, multispecific antibodies (e.g. bispecific antibodies) formed from at least two intact antibodies, and antibody fragments, so long as they exhibit the desired biological activity. The term generally includes heteroantibodies which are composed of two or more antibodies or fragments thereof of different binding specificity which are linked together.

Depending on the amino acid sequence of their constant regions, intact antibodies can be assigned to different "*antibody (immunoglobulin) classes*". There are five major classes of intact antibodies: IgA, IgD, IgE, IgG, and IgM, and several of these may be further divided into "subclasses" (isotypes), e.g., IgG1, IgG2, IgG3, IgG4, IgA, and IgA2. The heavy-chain constant domains that correspond to the different classes of antibodies are called α , δ , ϵ , γ and μ respectively. Preferred major class for antibodies according to the invention is IgG, in more detail IgG1 and IgG2.

Antibodies are usually glycoproteins having a molecular weight of about 150,000, composed of two identical light (L) chains and two identical heavy (H) chains. Each light chain is linked to a heavy chain by one covalent disulfide bond, while the number of disulfide linkages varies among the heavy chains of different immunoglobulin isotypes. Each heavy and light chain also has regularly spaced intrachain disulfide bridges. Each heavy chain has at one end a variable domain (VH) followed by a number of constant domains. Each light chain has a variable domain at one end (VL) and a constant domain at its other end. The constant domain of the light chain is aligned with the first constant domain of the heavy chain, and the light-chain variable domain is aligned with

the variable domain of the heavy chain. Particular amino acid residues are believed to form an interface between the light chain and heavy chain variable domains. The "light chains" of antibodies from any vertebrate species can be assigned to one of two clearly distinct types, called kappa (κ) and lambda (λ), based on the amino acid sequences of their constant domains.

The term "*monoclonal antibody*" as used herein refers to an antibody obtained from a population of substantially homogeneous antibodies, *i.e.*, the individual antibodies comprising the population are identical except for possible naturally occurring mutations that may be present in minor amounts. Monoclonal antibodies are highly specific, being directed against a single antigenic site. Furthermore, in contrast to polyclonal antibody preparations which include different antibodies directed against different determinants (epitopes), each monoclonal antibody is directed against a single determinant on the antigen. In addition to their specificity, the monoclonal antibodies are advantageous in that they may be synthesized uncontaminated by other antibodies. Methods for making monoclonal antibodies include the hybridoma method described by Kohler and Milstein (1975, *Nature* 256, 495) and in "Monoclonal Antibody Technology, The Production and Characterization of Rodent and Human Hybridomas" (1985, Burdon et al., Eds, Laboratory Techniques in Biochemistry and Molecular Biology, Volume 13, Elsevier Science Publishers, Amsterdam), or may be made by well known recombinant DNA methods (see, e.g., US 4,816,567). Monoclonal antibodies may also be isolated from phage antibody libraries using the techniques described in Clackson *et al.*, *Nature*, 352:624-628 (1991) and Marks *et al.*, *J. Mol. Biol.*, 222:58, 1-597(1991), for example.

The term "*chimeric antibody*" means antibodies in which a portion of the heavy and/or light chain is identical with or homologous to corresponding sequences in antibodies derived from a particular species or belonging to a particular antibody class or subclass, while the remainder of the chain(s) is identical with or homologous to corresponding sequences in antibodies derived from another species or belonging to another antibody class or subclass, as well as fragments of such antibodies, so long as they exhibit the desired biological activity (e.g.: US 4,816,567; Morrison et al., *Proc. Nat. Acad. Sci. USA*, 81:6851-6855 (1984)). Methods for making chimeric and humanized antibodies are also known in the art. For example, methods for making chimeric antibodies include those

described in patents by Boss (Celltech) and by Cabilly (Genentech) (US 4,816,397; US 4,816,567).

5 *"Humanized antibodies"* are forms of non-human (e.g., rodent) chimeric antibodies that contain minimal sequence derived from non-human immunoglobulin. For the most part, humanized antibodies are human immunoglobulins (recipient antibody) in which residues from a hypervariable region (CDRs) of the recipient are replaced by residues from a hypervariable region of a non-human species (donor antibody) such as mouse, rat, rabbit or nonhuman primate having the desired specificity, affinity and capacity. In some
10 instances, framework region (FR) residues of the human immunoglobulin are replaced by corresponding non-human residues. Furthermore, humanized antibodies may comprise residues that are not found in the recipient antibody or in the donor antibody. These modifications are made to further refine antibody performance. In general, the humanized antibody will comprise substantially all of at least one, and typically two,
15 variable domains, in which all or substantially all of the hypervariable loops correspond to those of a non-human immunoglobulin and all or substantially all of the FRs are those of a human immunoglobulin sequence. The humanized antibody optionally also will comprise at least a portion of an immunoglobulin constant region (Fc), typically that of a human immunoglobulin. Methods for making humanized antibodies are described, for
20 example, by Winter (US 5,225,539) and Boss (Celltech, US 4,816,397).

"Antibody fragments" comprise a portion of an intact antibody, preferably comprising the antigen-binding or variable region thereof. Examples of antibody fragments include Fab, Fab', F(ab')₂, Fv and Fc fragments, diabodies, linear antibodies, single-chain antibody
25 molecules; and multispecific antibodies formed from antibody fragment(s). An "intact" antibody is one which comprises an antigen-binding variable region as well as a light chain constant domain (CL) and heavy chain constant domains, CH1, CH2 and CH3. Preferably, the intact antibody has one or more effector functions. Papain digestion of antibodies produces two identical antigen-binding fragments, called "Fab" fragments,
30 each comprising a single antigen-binding site and a CL and a CH1 region, and a residual "Fc" fragment, whose name reflects its ability to crystallize readily.

The "Fc" region of the antibodies comprises, as a rule, a CH2, CH3 and the hinge region of an IgG1 or IgG2 antibody major class. The hinge region is a group of about 15 amino acid residues which combine the CH1 region with the CH2-CH3 region.

Pepsin treatment yields an "*F(ab')₂*" fragment that has two antigen-binding sites and is still capable of cross-linking antigen.

"*Fv*" is the minimum antibody fragment which contains a complete antigen-recognition and antigen-binding site. This region consists of a dimer of one heavy chain and one light chain variable domain in tight, non-covalent association. It is in this configuration that the three hypervariable regions (CDRs) of each variable domain interact to define an antigen-binding site on the surface of the VH - VL dimer. Collectively, the six hypervariable regions confer antigen-binding specificity to the antibody. However, even a single variable domain (or half of an *Fv* comprising only three hypervariable regions specific for an antigen) has the ability to recognize and bind antigen, although at a lower affinity than the entire binding site.

The "*Fab*" fragment also contains the constant domain of the light chain and the first constant domain (CH1) of the heavy chain and has one antigen-binding site only.

"*Fab'*" fragments differ from *Fab* fragments by the addition of a few residues at the carboxy terminus of the heavy chain CH1 domain including one or more cysteines from the antibody hinge region.

F(ab')₂ antibody fragments originally were produced as pairs of *Fab'* fragments which have hinge cysteines between them. Other chemical couplings of antibody fragments are also known (see e.g. Hermanson, *Bioconjugate Techniques*, Academic Press, 1996; US 4,342,566).

"*Single-chain Fv*" or "*scFv*" antibody fragments comprise the V_H and V_L domains of antibody, wherein these domains are present in a Single polypeptide chain. Preferably, the *Fv* polypeptide further comprises a polypeptide linker between the VH and VL domains which enables the *scFv* to form the desired structure for antigen binding. Single-chain *FV* antibodies are known, for example, from Plückthun (*The Pharmacology of Monoclonal Antibodies*, Vol. 113, Rosenberg and Moore eds., Springer-Verlag, New York, pp. 269-315 (1994)), WO93/16185; US 5,571,894; US 5,587,458; Huston et al. (1988, *Proc.Natl. Acad. Sci.* 85, 5879) or Skerra and Plueckthun (1988, *Science* 240, 1038).

The term "*variable*" or "*FR*" refers to the fact that certain portions of the variable domains differ extensively in sequence among antibodies and are used in the binding and specificity of each particular antibody for its particular antigen. However, the variability is not evenly distributed throughout the variable domains of antibodies. It is concentrated in three segments called "*hypervariable*" regions both in the light chain and the heavy

chain variable domains. The more highly conserved portions of variable domains are called the framework regions (FRs). The variable domains of native heavy and light chains each comprise four FRs (FR1 – FR4), largely adopting a β -sheet configuration, connected by three hypervariable regions, which form loops connecting, and in some cases forming part of, the β -sheet structure. The hypervariable regions in each chain are held together in close proximity by the FRs and, with the hypervariable regions from the other chain, contribute to the formation of the antigen-binding site of antibodies (see Kabat *et al.*, *Sequences of Proteins of Immunological Interest*, 5th Ed. Public Health Service, National Institutes of Health, Bethesda, MD. (1991)). The constant domains are not involved directly in binding an antibody to an antigen, but exhibit various effector functions, such as participation of the antibody in antibody dependent cellular cytotoxicity (ADCC).

The term “*hypervariable region*” or “*CDR*” when used herein refers to the amino acid residues of an antibody which are responsible for antigen-binding. The hypervariable region generally comprises amino acid residues from a “complementarity determining region” or “*CDR*” (e.g. residues 24-34 (L1), 50-56 (L2) and 89-97 (L3) in the light chain variable domain and 31-35 (H1), 50-65 (H2) and 95-102 (H3) in the heavy chain variable domain; and/or those residues from a “hypervariable loop” (e.g. residues 26-32 (L1), 50-52 (L2) and 91-96 (L3) in the light chain variable domain and 26-32 (H1), 53-55 (H2) and 96-101 (H3) in the heavy chain variable domain; Chothia and Lesk *J. Mol. Biol.* 196:901-917 (1987)). “*Framework Region*” or “*FR*” residues are those variable domain residues other than the hypervariable region residues as herein defined.

The term “*monospecific*” refers to antibodies according to this invention, wherein the two binding sites of the antibody have the same specificity, thus, being able to bind to the same epitope on the receptor. Preferably, according to this invention, the pharmaceutical compositions comprise monospecific antibodies.

“*Bispecific antibodies*” (BAbs) are single, divalent antibodies (or immunotherapeutically effective fragments thereof) which have two differently specific antigen binding sites. According to this invention BAbs are characterized as BAb <MAb 1, MAb 2>, wherein <MAb 1> and <MAb 2> designates the antigen-binding sites deriving from MAb 1 and MAb 2. For example the first antigen binding site is directed to an angiogenesis receptor (e.g. integrin or VEGF receptor), whereas the second antigen binding site is directed to an

ErbB receptor (e.g. EGFR or HER2). Bispecific antibodies can be produced by chemical techniques (see e.g., Kranz et al. (1981) Proc. Natl. Acad. Sci. USA 78, 5807), by "polydoma" techniques (See US 4,474,893) or by recombinant DNA techniques, which all are known per se. Further methods are described in WO 91/00360, WO 92/05793 and
5 WO 96/04305. Bispecific antibodies can also be prepared from single chain antibodies (see e.g., Huston et al. (1988) Proc. Natl. Acad. Sci. 85, 5879; Skerra and Plueckthun (1988) Science 240, 1038). These are analogues of antibody variable regions produced as a single polypeptide chain. To form the bispecific binding agent, the single chain antibodies may be coupled together chemically or by genetic engineering methods known
10 in the art. It is also possible to produce bispecific antibodies according to this invention by using leucine zipper sequences. The sequences employed are derived from the leucine zipper regions of the transcription factors Fos and Jun (Landschulz et al., 1988, Science 240,1759; for review, see Maniatis and Abel, 1989, Nature 341, 24). Leucine zippers are specific amino acid sequences about 20-40 residues long with leucine typically
15 occurring at every seventh residue. Such zipper sequences form amphipathic α -helices, with the leucine residues lined up on the hydrophobic side for dimer formation. Peptides corresponding to the leucine zippers of the Fos and Jun proteins form heterodimers preferentially (O'Shea et al., 1989, Science 245, 646). Zipper containing bispecific antibodies and methods for making them are also disclosed in WO 92/10209 and WO
20 93/11162.

The term "*fusion protein*" refers to a natural or synthetic molecule consisting of one or more biological molecules as defined above, wherein two or more peptide- or protein-based (glycoproteins included) molecules having different specificity are fused together
25 optionally by chemical or amino acid based linker molecules. The linkage may be achieved by C-N fusion or N-C fusion (in 5' \rightarrow 3' direction), preferably C-N fusion. Preferred fusion proteins according to the invention are, however, immunoconjugates as defines below.

30 The term "*immunoconjugate*" refers to a fusion protein and means an antibody or immunoglobulin, respectively, or a immunologically effective fragment thereof, which is fused by covalent linkage to a non-immunologically effective molecule. Preferably this fusion partner is a peptide or a protein, which may be glycosylated. Said non-antibody

molecule can be linked to the C-terminal of the constant heavy chains of the antibody or to the N-terminals of the variable light and/or heavy chains. The fusion partners can be linked via a linker molecule, which is, as a rule, a 3 – 15 amino acid residues containing peptide. Immunoconjugates according to this invention are fusion proteins consisting of
5 an immunoglobulin or immunotherapeutically effective fragment thereof, directed to an ErbB receptor, and preferably a cytokine, such as TNF α , IFN γ or IL-2, or another toxic agent. Preferably, these peptide- or protein-based molecules are linked with their N-terminal to the C-terminal of said immunoglobulin, which is the Fc portion thereof.

10 "*Heteroantibodies*" are fusion proteins consisting essentially of two or more antibodies or antibody-binding fragments which are fused together by regularly chemical cross-linkers, each of said antibodies having a different binding specificity. Heteroantibodies can be prepared by conjugating together two or more antibodies or antibody fragments. Preferred heteroantibodies are comprised of cross-linked Fab/Fab' fragments. A variety
15 of coupling or cross-linking agents can be used to conjugate the antibodies. Examples are protein A, carbodiimide, N-succinimidyl-S-acetyl-thioacetate (SATA) and N-succinimidyl-3-(2-pyridyldithio) propionate (SPDP) (see e.g., Karpovsky et al. (1984) J. EXP. Med. 160,1686; Liu et al. (1985) Proc. Natl. Acad. Sci. USA 82, 8648). Other methods include those described by Paulus, Behring Inst. Mitt., No. 78, 118 (1985); Brennan et al.
20 (1985) Science 30, 81, or Glennie et al. (1987), J. Immunol. 139, 2367. Another method uses o-phenylenedimaleimide (oPDM) for coupling three Fab' fragments (WO 91/03493). Multispecific antibodies are in context of this invention also suitable and can be prepared, for example according to the teaching of WO 94/13804 and WO 98/50431. A preferred heteroantibody according to this invention is a fusion protein comprising two anti-EGFR
25 antibodies (each antibody is directed to different epitopes of the same receptor) linked together as described (e.g. MAB 425 – MAB 225).

The term "*cytokine*" is a generic term for proteins released by one cell population which act on another cell as intercellular mediators. Examples of such cytokines are lymphokines, monokines, and traditional polypeptide hormones. Included among the
30 cytokines are growth hormone such as human growth hormone, N-methionyl human growth hormone, and bovine growth hormone; parathyroid hormone; thyroxine; insulin; proinsulin; relaxin; prorelaxin; glycoprotein hormones such as follicle stimulating hormone (FSH), thyroid stimulating hormone (TSH), and luteinizing hormone (LH);

- hepatic growth factor; fibroblast growth factor; prolactin; placental lactogen; mouse gonadotropin-associated peptide; inhibin; activin; vascular endothelial growth factor (VEGF); integrin; thrombopoietin (TPO); nerve growth factors such as NGF β ; platelet-growth factor; transforming growth factors (TGFs) such as TGF α and
- 5 TGF β ; erythropoietin (EPO); interferons such as IFN α , IFN β , and IFN γ ; colony stimulating factors such as M-CSF, GM-CSF and G-CSF; interleukins such as IL-1, IL-1a, IL-2, IL-3, IL-4, IL-5, IL-6, IL-7, IL-8, IL-9, IL-10, IL-11, IL-12; and TNF- α or TNF- β . Preferred cytokines according to the invention are interferons, TNF α and IL-2.
- 10 Antibody "*effector functions*" refer to those biological activities attributable to the Fc region (a native sequence Fc region or amino acid sequence variant Fc region) of an antibody. Examples of antibody effector functions include complement dependent cytotoxicity, Fc receptor binding, antibody-dependent cell-mediated cytotoxicity (ADCC), phagocytosis; down regulation of cell surface receptors (e.,g. B cell
- 15 receptor), etc.

The term "ADCC" (antibody-dependent cell-mediated cytotoxicity) refers to a cell-mediated reaction in which nonspecific cytotoxic cells that express Fc receptors (FcR) (e.g. natural killer (NK) cells, neutrophils, and macrophages) recognize bound antibody

20 on a target cell and subsequently cause lysis of the target cell. The primary cells for mediating ADCC, NK cells, express Fc γ RIII only, whereas monocytes express Fc γ RI, Fc γ RII and Fc γ RIII. To assess ADCC activity of a molecule of interest, an *in vitro* ADCC assay, such as that described in the prior art (US 5,500,362; US 5,821,337) may be performed. Useful effector cells for such assays include peripheral blood mononuclear

25 cells (PBMC) and natural killer (NK) cells.

The terms "*Fc receptor*" or "FcR" are used to describe a receptor that binds to the Fc region of an antibody. The preferred FcR is a native sequence human FcR. Moreover, a preferred FcR is one which binds an IgG antibody (a gamma receptor) and includes receptors of the Fc γ RI, Fc γ RII, and Fc γ RIII subclasses, including allelic variants and

30 alternatively spliced forms of these receptors. FcRs are reviewed, for example, in Ravetch and Kinet, *Annu. Rev. Immunol* 9:457-92 (1991).

The therapeutic approach of this invention includes as a specific embodiment the administration of further therapeutically effective agents, which support the desired effect, e.g. tumor toxicity or cytostatic efficacy, or diminish or prevent undesired side effects. Thus the invention includes the combination of such agents with the

5 pharmaceutical composition defined and claimed above and below, wherein said agents may be other ErbB receptor antagonists, VEGF receptor antagonists, cytokines, cytokine-immunoconjugates, anti-angiogenic agents, anti-hormonal agents, or cytotoxic agents in general. It is also an object of this invention to combine the compositions as defined herein with radiotherapy according to known methods.

10

The term "*cytotoxic agent*" as used in this context is defined very broadly and refers to a substance that inhibits or prevents the function of cells and / or causes destruction of cells (cell death), and / or exerts anti-neoplastic / anti-proliferative effects, for example, prevents directly or indirectly the development, maturation or spread of neoplastic tumor

15 cells. The term includes expressively also such agents that cause a cytostatic effect only and not a mere cytotoxic effect. The term includes chemotherapeutic agents as specified below, as well as other ErbB antagonists (such as anti-ErbB antibodies), anti-angiogenic agents, tyrosine kinase inhibitors, protein kinase A inhibitors, members of the cytokine family, radioactive isotopes, and toxins such as enzymatically active toxins of bacterial,

20 fungal, plant or animal origin.

The term "*chemotherapeutic agent*" is a subset of the term "cytotoxic agent" and means specifically chemical agents that exert anti-neoplastic effects, preferably directly on the tumor cell, and less indirectly through mechanisms such as biological response

25 modification. Suitable chemotherapeutic agents according to the invention are preferably natural or synthetic chemical compounds. There are large numbers of anti-neoplastic chemical agents available in commercial use, in clinical evaluation and in pre-clinical development, which could be included in the present invention for treatment of tumors / neoplasia by combination therapy with the receptor antagonists as claimed and

30 described in this invention. It should be pointed out that the chemotherapeutic agents can be administered optionally together with said ErbB receptor antagonists, preferably said anti-EGFR antibodies, according to the invention.

Examples of chemotherapeutic agents include alkylating agents, for example, nitrogen mustards, ethyleneimine compounds, alkyl sulphonates and other compounds with an

alkylating action such as nitrosoureas, cisplatin and dacarbazine; antimetabolites, for example, folic acid, purine or pyrimidine antagonists; mitotic inhibitors, for example, vinca alkaloids and derivatives of podophyllotoxin; cytotoxic antibiotics and camptothecin derivatives.

- 5 Preferred chemotherapeutic agents are amifostine (ethiol), cisplatin, dacarbazine (DTIC), dactinomycin, mechlorethamine (nitrogen mustard), streptozocin, cyclophosphamide, carmustine (BCNU), lomustine (CCNU), doxorubicin (adriamycin), doxorubicin lipo (doxil), gemcitabine (gemzar), daunorubicin, daunorubicin lipo (daunoxome), procarbazine, mitomycin, cytarabine, etoposide, methotrexate, 5-fluorouracil (5-FU),
10 vinblastine, vincristine, bleomycin, paclitaxel (taxol), docetaxel (taxotere), aldesleukin, asparaginase, busulfan, carboplatin, cladribine, camptothecin, CPT-11, 10-hydroxy-7-ethyl-camptothecin (SN38), gefitinib (Iressa), dacarbazine, floxuridine, fludarabine, hydroxyurea, ifosfamide, idarubicin, mesna, interferon alpha, interferon beta, irinotecan, mitoxantrone, topotecan, leuprolide, megestrol, melphalan, mercaptopurine, plicamycin,
15 mitotane, pegaspargase, pentostatin, pipobroman, plicamycin, streptozocin, tamoxifen, teniposide, testolactone, thioguanine, thiotepa, uracil mustard, vinorelbine, chlorambucil and combinations thereof.

Most preferred chemotherapeutic agents according to the invention are cisplatin, gemcitabine, doxorubicin, paclitaxel (taxol) and bleomycin.

20

- An "*anti-angiogenic agent*" refers to a natural or synthetic compound which blocks, or interferes with to some degree, the development of blood vessels. The anti-angiogenic molecule may, for instance, be a biological molecule that binds to and blocks an angiogenic growth factor or growth factor receptor. The preferred anti-angiogenic
25 molecule herein binds to an receptor, preferably to an integrin receptor or to VEGF receptor. The term includes according to the invention also a prodrug of said angiogenic agent. The term furthermore includes agents effective as described and also classified as cytotoxic, preferably, chemotherapeutic agents.

- There are a lot of molecules having different structure and origin which elicit anti-
30 agiogenic properties. Most relevant classes of angiogenesis inhibiting or blocking agents which are suitable in this invention, are, for example:

- (i) *anti-mitotics* such as flurouracil, mytomycin-C, taxol;
- (ii) *estrogen metabolites* such as 2-methoxyestradiol;
- (iii) *matrix metalloproteinase (MMP) inhibitors*, which inhibit zinc metalloproteinases

metalloproteases) (e.g. betimastat, BB16, TIMPs, minocycline, GM6001, or those described in "Inhibition of Matrix Metalloproteinases: Therapeutic Applications" (Golub, Annals of the New York Academy of Science, Vol. 878a; Greenwald, Zucker (Eds.), 1999);

- 5 (iv) *anti-angiogenic multi-functional agents and factors* such as IFN α (US 4,530,901; US 4,503,035; 5,231,176); angiostatin and plasminogen fragments (e.g. kringle 1-4, kringle 5; kringle 1-3 (O'Reilly, M. S. et al., *Cell (Cambridge, Mass.)* 79(2): 315-328, 1994; Cao et al., *J. Biol. Chem.* 271: 29461-29467, 1996; Cao et al., *J. Biol. Chem* 272: 22924 -22928, 1997); endostatin (O'Reilly, M. S. et al., *Cell* 10 88(2), 277, 1997 and WO 97/15666), thrombospondin (TSP-1; Frazier, 1991, *Curr Opin Cell Biol* 3(5): 792); platelet factor 4 (PF4);
- (v) *plasminogen activator/urokinase inhibitors*;
- (vi) *urokinase receptor antagonists*;
- (vii) *heparinases*;
- 15 (viii) *fumagillin analogs* such as TNP-470;
- (ix) *tyrosine kinase inhibitors* such as SU10. Many of the above and below mentioned ErbB receptor antagonists (EGFR / HER2 antagonists) are also tyrosine kinase inhibitors, and may show, therefore anti-EGF receptor blocking activity which results in inhibiting tumor growth, as well as anti-angiogenic activity which results
- 20 in inhibiting the development of blood vessels and endothelial cells, respectively;
- (x) *suramin and suramin analogs*;
- (xi) *angiostatic steroids*;
- (xii) *VEGF and bFGF antagonists*;
- (xiii) *VEGF receptor antagonists* such as anti-VEGF receptor antibodies (DC-101);
- 25 (xiv) *flk-1 and flt-1 antagonists*;
- (xv) *cyclooxygenase-II inhibitors* such as COX-II;
- (xvi) *integrin antagonists and integrin receptor antagonists* such as α_v antagonists and α_v receptor antagonists, for example, anti- α_v receptor antibodies and RGD peptides. Integrin (receptor) antagonists are preferred according to this invention.
- 30 The term "*integrin antagonists / inhibitors*" or "*integrin receptor antagonists / inhibitors*" refers to a natural or synthetic molecule that blocks and inhibit an integrin receptor. In some cases, the term includes antagonists directed to the ligands of said integrin receptors (such as for $\alpha_v\beta_3$: vitronectin, fibrin, fibrinogen,

von Willebrand's factor, thrombospondin, laminin; for $\alpha_v\beta_5$: vitronectin; for $\alpha_v\beta_1$: fibronectin and vitronectin; for $\alpha_v\beta_6$: fibronectin).

Antagonists directed to the integrin receptors are preferred according to the invention. Integrin (receptor) antagonists may be natural or synthetic peptides,
5 non-peptides, peptidomimetica, immunoglobulins, such as antibodies or functional fragments thereof, or immunoconjugates (fusion proteins).

Preferred integrin inhibitors of the invention are directed to receptor of α_v integrins (e.g. $\alpha_v\beta_3$, $\alpha_v\beta_5$, $\alpha_v\beta_6$ and sub-classes). Preferred integrin inhibitors are α_v antagonists, and in particular $\alpha_v\beta_3$ antagonists. Preferred α_v antagonists
10 according to the invention are RGD peptides, peptidomimetic (non-peptide) antagonists and anti-integrin receptor antibodies such as antibodies blocking α_v receptors. Exemplary, non-immunological $\alpha_v\beta_3$ antagonists are described in the teachings of US 5,753,230 and US 5,766,591. Preferred antagonists are linear and cyclic RGD-containing peptides. Cyclic peptides are, as a rule, more stable
15 and elicit an enhanced serum half-life. The most preferred integrin antagonist of the invention is, however, cyclo-(Arg-Gly-Asp-DPhe-NMeVal) (EMD 121974, Cilengitide[®], Merck KgaA, Germany; EP 0770 622) which is efficacious in blocking the integrin receptors $\alpha_v\beta_3$, $\alpha_v\beta_1$, $\alpha_v\beta_6$, $\alpha_v\beta_8$, $\alpha_{IIb}\beta_3$.

Suitable peptidic as well as peptido-mimetic (non-peptide) antagonists of the $\alpha_v\beta_3$
20 / $\alpha_v\beta_5$ / $\alpha_v\beta_6$ integrin receptor have been described both in the scientific and patent literature. For example, reference is made to Hoekstra and Poulter, 1998, Curr. Med. Chem. 5, 195; WO 95/32710; WO 95/37655; WO 97/01540; WO 97/37655; WO 97/45137; WO 97/41844; WO 98/08840; WO 98/18460; WO 98/18461; WO 98/25892; WO 98/31359; WO 98/30542; WO 99/15506; WO 99/15507; WO
25 99/31061; WO 00/06169; EP 0853 084; EP 0854 140; EP 0854 145; US 5,780,426; and US 6,048,861. Patents that disclose benzazepine, as well as related benzodiazepine and benzocycloheptene $\alpha_v\beta_3$ integrin receptor antagonists, which are also suitable for the use in this invention, include WO 96/00574, WO 96/00730, WO 96/06087, WO 96/26190, WO 97/24119, WO 97/24122,
30 WO 97/24124, WO 98/15278, WO 99/05107, WO 99/06049, WO 99/15170, WO 99/15178, WO 97/34865, WO 97/01540, WO 98/30542, WO 99/11626, and WO 99/15508. Other integrin receptor antagonists featuring backbone conformational ring constraints have been described in WO 98/08840; WO

99/30709; WO 99/30713; WO 99/31099; WO 00/09503; US 5,919,792; US 5,925,655; US 5,981,546; and US 6,017,926. In US 6,048,861 and WO 00/72801 a series of nonanoic acid derivatives which are potent $\alpha_v\beta_3$ integrin receptor antagonists were disclosed. Other chemical small molecule integrin antagonists (mostly vitronectin antagonists) are described in WO 00/38665. Other $\alpha_v\beta_3$ receptor antagonists have been shown to be effective in inhibiting angiogenesis. For example, synthetic receptor antagonists such as (S)-10,11-Dihydro-3-[3-(pyridin-2-ylamino)-1-propyloxy]-5H-dibenzo[a,d]cycloheptene-10-acetic acid (known as SB-265123) have been tested in a variety of mammalian model systems. (Keenan et al., 1998, Bioorg. Med. Chem. Lett. 8(22), 3171; Ward et al., 1999, Drug Metab. Dispos. 27(11),1232). Assays for the identification of integrin antagonists suitable for use as an antagonist are described, e.g. by Smith et al., 1990, J. Biol. Chem. 265, 12267, and in the referenced patent literature. Anti-integrin receptor antibodies are also well known. Suitable anti-integrin (e.g. $\alpha_v\beta_3$, $\alpha_v\beta_5$, $\alpha_v\beta_6$) monoclonal antibodies can be modified to encompass antigen binding fragments thereof, including F(ab)₂, Fab, and engineered Fv or single-chain antibody. One suitable and preferably used monoclonal antibody directed against integrin receptor $\alpha_v\beta_3$ is identified as LM609 (Brooks et al., 1994, Cell 79, 1157; ATCC HB 9537). A potent specific anti- $\alpha_v\beta_5$ antibody, P1F6, is disclosed in WO 97/45447, which is also preferred according to this invention. A further suitable $\alpha_v\beta_6$ selective antibody is MAb 14D9.F8 (WO 99/37683, DSM ACC2331, Merck KGaA, Germany) as well as MAb 17.E6 (EP 0719 859, DSM ACC2160, Merck KGaA) which is selectively directed to the α_v - chain of integrin receptors. Another suitable anti-integrin antibody is the commercialized Vitroxin®.

As used herein, the term "*anti-hormonal agent*" includes natural or synthetic organic or peptidic compounds that act to regulate or inhibit hormone action on tumors. In more detail an "*anti-hormonal agent*" (1) inhibits the production of serum androgens, (2) blocks binding of serum androgens to androgen receptors, or (3) inhibits the conversion of testosterone to DHT, or a combination of two or more such compounds. An anti-hormonal agent according to the invention includes in general steroid receptor antagonists and in more detail anti-estrogens including for example tamoxifen, raloxifene, aromatase

inhibiting 4(5)-imidazoles, 4-hydroxytamoxifen, trioxifene, keoxifene, LY 117018, onapristone, and toremifene (Fareston); and anti-androgens such as flutamide, nilutamide, bicalutamide, leuprolide, and goserelin; and pharmaceutically acceptable salts, acids or derivatives of any of the above. The term includes also agonists and / or

5 antagonists of glycoprotein hormones such as follicle stimulating hormone (FSH), thyroid stimulating hormone (TSH), and luteinizing hormone (LH) and LHRH (leuteinizing hormone - releasing hormone). A LHRH agonist useful in this invention is goserelin acetate, commercially available as ZOLADEX® (Zeneca). Another example of a useful LHRH antagonist is GANIRELIX® (Roche/Akzo Nobel). Examples of steroidal anti-

10 androgens are cyproterone acetate (CPA) and megestrol acetate, commercially available as MEGACE® (Bristol-Myers Oncology). Steroidal anti-androgens may block prostatic androgen receptors. They may also inhibit the release of LH. CPA is preferably administered to human patients at dosages of 100 mg/day to 250 mg/day. Nonsteroidal anti-androgens block androgen receptors. They may also cause an increase in serum

15 LH levels and Serum testosterone levels. A preferred nonsteroidal anti-androgen is flutamide (2-methyl-N-[4- 20 nitro-3-(trifluoromethyl)phenyl] propanamide), commercially available as EULEXIN® (Schering Corp.). Flutamide exerts is anti-androgenic action by inhibiting androgen uptake, by inhibiting nuclear binding of androgen in target tissues, or both. Another non-steroidal anti-androgen is nilutamide,

20 whose chemical name is 5,5-dimethyl-3-[4-nitro-3- (trifluoromethyl -4'-nitrophenyl)-4,4-dimethyl-imidazolidine-dione. In some embodiments of the invention, the anti-hormonal agent is a combination of an LHRH agonist such as leuprolide acetate, and an antiandrogen such as flutamide or nilutamide. For example, leuprolide acetate can be administered by subcutaneous, intramuscular or intravenous injection, and concurrently

25 the flutamide can be administered orally. Anti-hormonal agents according to the invention include, as pointed out above, antagonists of the steroid/thyroid hormone receptors, including antagonists for other non-permissive receptors, such as antagonists for RAR, TR, VDR, and the like. As readily recognized by those of skill in the art, a variety of retinoic acid receptor (RAR) antagonists, both synthetic and naturally occurring, can be

30 used in accordance with the present invention.

The bispecific antibodies according to this invention can be combined with other drugs. These drugs can be preferably selected as follows:

- tyrosine kinase inhibitors, such as Iressa®;

- anti-angiogenic agents, preferably integrin inhibitors, more preferably RGD peptides, cyclic peptides included, such as cyclo-(Arg-Gly-Asp-DPhe-NMeVal) (Cilengitide[®], Merck KGaA);
- anti-VEGF receptor antibodies, such as DC-101, or VEGF antagonists;
- 5 • COX-II inhibitors;
- cytokines, such as TNF- α , IFN- α , IFN- β , IFN- γ , IL-2;
- type I protein kinase A (PKA) inhibitors, such as mixed backbone antisense oligonucleotides, like HYB 165 (see, for example, Tortora et al., 1999, Clin. Cancer Res., 875-881);
- 10 • anti-hormonal agents, such as goserelin, boserelin, leuporelin, tamoxifen.

The terms "*cancer*" and "*tumor*" refer to or describe the physiological condition in mammals that is typically characterized by unregulated cell growth. By means of the pharmaceutical compositions according of the present invention tumors can be treated

15 such as tumors of the breast, heart, lung, small intestine, colon, spleen, kidney, bladder, head and neck, ovary, prostate, brain, pancreas, skin, bone, bone marrow, blood, thymus, uterus, testicles, cervix, and liver. More specifically the tumor is selected from the group consisting of adenoma, angio-sarcoma, astrocytoma, epithelial carcinoma, germinoma, glioblastoma, glioma, hamartoma, hemangioendothelioma, hemangiosarcoma, hematoma,

20 hepato-blastoma, leukemia, lymphoma, medulloblastoma, melanoma, neuroblastoma, osteosarcoma, retinoblastoma, rhabdomyosarcoma, sarcoma and teratoma. In detail, the tumor is selected from the group consisting of acral lentiginous melanoma, actinic keratoses, adenocarcinoma, adenoid cystic carcinoma, adenomas, adenocarcinoma, adenosquamous carcinoma, astrocytic tumors, bartholin gland carcinoma, basal cell

25 carcinoma, bronchial gland carcinomas, capillary, carcinoids, carcinoma, carcinosarcoma, cavernous, cholangio-carcinoma, chondrosarcoma, choroid plexus papilloma/carcinoma, clear cell carcinoma, cystadenoma, endodermal sinus tumor, endometrial hyperplasia, endometrial stromal sarcoma, endometrioid adenocarcinoma, ependymal, epitheloid, Ewing's sarcoma, fibrolamellar, focal nodular hyperplasia, gastrinoma, germ cell tumors,

30 glioblastoma, glucagonoma, hemangiblastomas, hemangioendothelioma, hemangiomas, hepatic adenoma, hepatic adenomatosis, hepatocellular carcinoma, insulinoma, intraepithelial neoplasia, interepithelial squamous cell neoplasia, invasive squamous cell carcinoma, large cell carcinoma, leiomyosarcoma, lentigo maligna melanomas, malignant

melanoma, malignant mesothelial tumors, medulloblastoma, medulloepithelioma, melanoma, meningeal, mesothelial, metastatic carcinoma, mucoepidermoid carcinoma, neuroblastoma, neuroepithelial adenocarcinoma nodular melanoma, oat cell carcinoma, oligodendroglial, osteosarcoma, pancreatic polypeptide, papillary serous adeno-
5 carcinoma, pineal cell, pituitary tumors, plasmacytoma, pseudo-sarcoma, pulmonary blastoma, renal cell carcinoma, retinoblastoma, rhabdomyo-sarcoma, sarcoma, serous carcinoma, small cell carcinoma, soft tissue carcinomas, somatostatin-secreting tumor, squamous carcinoma, squamous cell carcinoma, submesothelial, superficial spreading melanoma, undifferentiated carcinoma, uveal melanoma, vermucous
10 carcinoma, vipoma, well differentiated carcinoma, and Wilm's tumor.

Tumors which can be preferably be treated with the antibody molecules according to the invention are solid tumors or tumor metastases that express ErbB receptors, especially ErbB1 receptors, in high amounts, such as breast cancer, prostate cancer head and neck
15 cancer, SCLC, pancreas cancer.

The term "*biologically/functionally effective*" or "*therapeutically effective (amount)*" refers to a drug / molecule which causes a biological function or a change of a biological function in vivo or in vitro, and which is effective in a specific amount to treat a disease
20 or disorder in a mammal, preferably in a human. In the case of cancer, the therapeutically effective amount of the drug may reduce the number of cancer cells; reduce the tumor size; inhibit (i.e., slow to some extent and preferably stop) cancer cell infiltration into peripheral organs; inhibit (i.e., slow to some extent and preferably stop) tumor metastasis; inhibit, to some extent, tumor growth; and/or relieve to some extent one or more of the
25 symptoms associated with the cancer. To the extent the drug may prevent growth and/or kill existing cancer cells, it may be cytostatic and/or cytotoxic. For cancer therapy, efficacy can, for example, be measured by assessing the time to disease progression (TTP) and/or determining the response rate (RR).

30 The term "*immunotherapeutically effective*" refers to biological molecules which cause an immune response in a mammal. More specifically, the term refers to molecules which may recognize and bind an antigen. Typically, antibodies, antibody fragments and antibody fusion proteins comprising their antigen binding sites (complementary determining regions, CDRs) are immunotherapeutically effective.

"Radiotherapy": According to the invention the tumors can additionally be treated with radiation or radiopharmaceuticals. The source of radiation can be either external or internal to the patient being treated. When the source is external to the patient, the therapy is known as external beam radiation therapy (EBRT). When the source of radiation is internal to the patient, the treatment is called brachytherapy (BT). Some typical radioactive atoms that have been used include radium, cesium-137, and iridium-192, americium-241 and gold-198, Cobalt-57; Copper-67; Technetium-99; Iodide-123; Iodide-131; and Indium-111. It is also possible to label the agents according to the invention with radioactive isotopes. Today radiation therapy is the standard treatment to control unresectable or inoperable tumors and / or tumor metastases. Improved results have been seen when radiation therapy has been combined with chemotherapy. Radiation therapy is based on the principle that high-dose radiation delivered to a target area will result in the death of reproductive cells in both tumor and normal tissues. The radiation dosage regimen is generally defined in terms of radiation absorbed dose (rad), time and fractionation, and must be carefully defined by the oncologist. The amount of radiation a patient receives will depend on various consideration but the two most important considerations are the location of the tumor in relation to other critical structures or organs of the body, and the extent to which the tumor has spread. A preferred course of treatment for a patient undergoing radiation therapy will be a treatment schedule over a 5 to 6 week period, with a total dose of 50 to 60 Gy administered to the patient in a single daily fraction of 1.8 to 2.0 Gy, 5 days a week. A Gy is an abbreviation for Gray and refers to a dose of 100 rad. If tumors are treated with the anti-ErbB antibodies as described in this invention in context with a radiation regimen, usually a positive and even synergistic effect can be observed. In other words, the inhibition of tumor growth by means of said compounds is enhanced when combined with radiation and / or chemotherapeutic agents. Radiation therapy can be optionally used according to the invention. It is recommended and preferred in cases in which no sufficient amounts of the agents according to the invention can be administered to the patient.

"Pharmaceutical treatment": The method of the invention comprises a variety of modalities for practicing the invention in terms of the steps. For example, the agents according to the invention can be administered simultaneously, sequentially, or separately. Furthermore, the agents can be separately administered within a time interval of about 3 weeks between administrations, i.e., from substantially

immediately after the first active agent is administered to up to about 3 weeks after the first agent is administered. The method can be practiced following a surgical procedure. Alternatively, the surgical procedure can be practiced during the interval between administration of the first active agent and the second active agent. Exemplary of
5 this method is the combination of the present method with surgical tumor removal. Treatment according to the method will typically comprise administration of the therapeutic compositions in one or more cycles of administration. For example, where a simultaneous administration is practiced, a therapeutic composition comprising both agents is administered over a time period of from about 2 days to about 3 weeks in a
10 single cycle. Thereafter, the treatment cycle can be repeated as needed according to the judgment of the practicing physician. Similarly, where a sequential application is contemplated, the administration time for each individual therapeutic will be adjusted to typically cover the same time period. The interval between cycles can vary from about zero to 2 months.

15 The agents of this invention can be administered parenterally by injection or by gradual infusion over time. Although the tissue to be treated can typically be accessed in the body by systemic administration and therefore most often treated by intravenous administration of therapeutic compositions, other tissues and delivery means are contemplated where there is a likelihood that the tissue targeted contains the target molecule. Thus, the agents
20 of this invention can be administered intraocularly, intravenously, intraperitoneally, intramuscularly, subcutaneously, intracavity, transdermally, by orthotopic injection and infusion, and can also be delivered by peristaltic means. The therapeutic compositions containing, for example, an integrin antagonist of this invention are conventionally administered intravenously, as by injection of a unit dose, for example.

25 Therapeutic compositions of the present invention contain a physiologically tolerable carrier together with the relevant agent as described herein, dissolved or dispersed therein as an active ingredient.

As used herein, the term "*pharmaceutically acceptable*" refers to compositions, carriers,
30 diluents and reagents which represent materials that are capable of administration to or upon a mammal without the production of undesirable physiological effects such as nausea, dizziness, gastric upset and the like. The preparation of a pharmacological composition that contains active ingredients dissolved or dispersed therein is well understood in the art and need not be limited based on formulation. Typically, such

compositions are prepared as injectables either as liquid solutions or suspensions, however, solid forms suitable for solution, or suspensions, in liquid prior to use can also be prepared. The preparation can also be emulsified. The active ingredient can be mixed with excipients which are pharmaceutically acceptable and compatible with the active
5 ingredient and in amounts suitable for use in the therapeutic methods described herein. Suitable excipients are, for example, water, saline, dextrose, glycerol, ethanol or the like and combinations thereof. In addition, if desired, the composition can contain minor amounts of auxiliary substances such as wetting or emulsifying agents, pH buffering agents and the like which enhance the effectiveness of the active ingredient. The
10 therapeutic composition of the present invention can include pharmaceutically acceptable salts of the components therein. Pharmaceutically acceptable salts include the acid addition salts (formed with the free amino groups of the polypeptide) that are formed with inorganic acids such as, for example, hydrochloric or phosphoric acids, or such organic acids as acetic, tartaric, mandelic and the like. Salts formed with the free carboxyl
15 groups can also be derived from inorganic bases such as, for example, sodium, potassium, ammonium, calcium or ferric hydroxides, and such organic bases as isopropylamine, trimethylamine, 2-ethylamino ethanol, histidine, procaine and the like. Particularly preferred is the HCl salt when used in the preparation of cyclic polypeptide α antagonists. Physiologically tolerable carriers are well known in the art. Exemplary of
20 liquid carriers are sterile aqueous solutions that contain no materials in addition to the active ingredients and water, or contain a buffer such as sodium phosphate at physiological pH value, physiological saline or both, such as phosphate-buffered saline. Still further, aqueous carriers can contain more than one buffer salt, as well as salts such as sodium and potassium chlorides, dextrose, polyethylene glycol and other
25 solutes. Liquid compositions can also contain liquid phases in addition to and to the exclusion of water. Exemplary of such additional liquid phases are glycerin, vegetable oils such as cottonseed oil, and water-oil emulsions.

Typically, a therapeutically effective amount of an immunotherapeutic agent, for
30 example, in the form of an ErbB (ErbB1) receptor blocking bispecific antibody, an integrin receptor blocking antibody or antibody fragment or antibody conjugate or an anti-VEGF receptor blocking antibody, fragment or conjugate is an amount such that, when administered in physiologically tolerable composition, is sufficient to achieve a

plasma concentration of from about 0.01 microgram (μg) per milliliter (ml) to about 100 $\mu\text{g/ml}$, preferably from about 1 $\mu\text{g/ml}$ to about 5 $\mu\text{g/ml}$ and usually about 5 $\mu\text{g/ml}$. Stated differently, the dosage can vary from about 0.1 mg/kg to about 300 mg/kg, preferably from about 0.2 mg/kg to about 200 mg/kg, most preferably from about 0.5 mg/kg to about 20 mg/kg, in one or more dose administrations daily for one or several days. Where the immunotherapeutic agent is in the form of a fragment of a monoclonal antibody or a conjugate, the amount can readily be adjusted based on the mass of the fragment / conjugate relative to the mass of the whole antibody. A preferred plasma concentration in molarity is from about 2 micromolar (μM) to about 5 millimolar (mM) and preferably, about 100 μM to 1 mM antibody antagonist.

A therapeutically effective amount of an agent according of this invention which is a non-immunotherapeutic peptide or a protein polypeptide or other similarly-sized biological molecule, is typically an amount of polypeptide such that when administered in a physiologically tolerable composition is sufficient to achieve a plasma concentration of from about 0.1 microgram (μg) per milliliter (ml) to about 200 $\mu\text{g/ml}$, preferably from about 1 $\mu\text{g/ml}$ to about 150 $\mu\text{g/ml}$. Based on a polypeptide having a mass of about 500 grams per mole, the preferred plasma concentration in molarity is from about 2 micromolar (μM) to about 5 millimolar (mM) and preferably about 100 μM to 1 mM polypeptide antagonist.

The typical dosage of an active agent, which is a preferably a chemical cytotoxic or chemotherapeutic agent according to the invention (neither an immunotherapeutic agent nor a non-immunotherapeutic peptide/protein) is 10 mg to 1000 mg, preferably about 20 to 200 mg, and more preferably 50 to 100 mg per kilogram body weight per day.

The pharmaceutical compositions of the invention can comprise phrase encompasses treatment of a subject with agents that reduce or avoid side effects associated with the combination therapy of the present invention ("adjunctive therapy"), including, but not limited to, those agents, for example, that reduce the toxic effect of anticancer drugs, e.g., bone resorption inhibitors, cardioprotective agents. Said adjunctive agents prevent or reduce the incidence of nausea and vomiting associated with chemotherapy, radiotherapy or operation, or reduce the incidence of infection associated with the administration of myelosuppressive anticancer drugs. Adjunctive agents are well known in the art. The immunotherapeutic agents according to the invention can additionally administered with adjuvants like BCG and immune system stimulators. Furthermore, the compositions may

include immunotherapeutic agents or chemotherapeutic agents which contain cytotoxic effective radio-labeled isotopes, or other cytotoxic agents, such as a cytotoxic peptides (e.g. cytokines) or cytotoxic drugs and the like.

- 5 The term "*pharmaceutical kit*" for treating tumors or tumor metastases refers to a package and, as a rule, instructions for using the reagents in methods to treat tumors and tumor metastases. A reagent in a kit of this invention is typically formulated as a therapeutic composition as described herein, and therefore can be in any of a variety of forms suitable for distribution in a kit. Such forms can include a liquid, powder, tablet, suspension and
- 10 the like formulation for providing the pharmaceutical molecules of this invention, preferably the anti-ErbB1 antibodies. The reagents may be provided in separate containers suitable for administration separately according to the present methods, or alternatively may be provided combined in a composition in a single container in the package. The package may contain an amount sufficient for one or more dosages of
- 15 reagents according to the treatment methods described herein. A kit of this invention also contains "instructions for use" of the materials contained in the package.

EXAMPLES

20

EXAMPLE 1:

PREPARATION OF F(AB')₂-FRAGMENTS OF MAB 425 AND MAB 225

- Anti-EGFR antibodies humanized MAb 425 and chimeric MAb 225 were converted into F(ab')₂-fragments by limited proteolysis. The generation of F(ab')₂ antibody had to be
- 25 optimized for each antibody. A general scheme used for the production is given below. Pepsin cleavage was best for both antibodies, however papain cleavage is also applicable. Residual complete antibody and Fc-fragments were removed with a Protein A sepharose column. The yield of F(ab')₂-fragment was close to 100%. The F(ab')₂-fragments can be stored at -20° C without any loss of activity for an extended time period.

General scheme:

*Growth fermentation → Centrifugation → Ultrafiltration → Protein A Chromatography
→ Dialysis /Ultrafiltration → Cleavage → Protein A Chromatography → Dialysis
/Ultrafiltration → F(ab')₂ product*

Details:

PBS, pH: 7.4

Protein Content: 5.06 mg/ml (Pierce).

Reagents: Tri-sodium citrate dihydrate, citric acid, tris(hydroxymethyl) aminomethane, pepsin, glycine, sodium chloride

5 Buffer Solutions:

0.1 M Na-Citrate buffer pH 3.5,

10 mg/mL pepsin in Na-citrate buffer pH 3.5,

1 M Tris pH 11

1.5 M glycine + 3 M NaCl pH 8.9

10 0.1 M citric acid pH 2.5

Procedure for Pepsin digestion:

pH and buffer conditions were adjusted by dialysis of MAbs over night in 0.1 M sodium citrate, pH: 3.5. Pepsin was added to the dialysed immunoglobulin in a ratio of 1:33 w/w. The mixture was continuously stirred at 37°C in a water bath. After 75 min the digest was
15 stopped by the addition of 7 ml of 1 M Tris-Solution. At this step the pH of the reaction should be set to approximately 8.5. This mixture was then transferred to a Protein A column in order to remove residual IgG and/or Fc-fragments.

Protein-A-Sepharose:

The pepsin digest was applied to an equilibrated Protein-A-Sepharose column and washed
20 with the equilibration buffer until the chromatogram returns to the base line. The flow through fractions were collected and the volume is reduced in an Amicon chamber (Membrane YM 30) and then dialysed against PBS pH: 7.4. Potential contaminants such as Fc-fragments or unmodified antibodies were eluted from the Protein-A-Sepharose column with 0.1 M citric acid pH: 2.5.

25 Chromatographic conditions:

Column bed size 5 cm x 2.5 cm. 1 ml of Protein A Sepharose is expected to bind 10 mg of IgG was equilibrated with 1.5 M glycine + 3 M NaCl pH: 8.9, flow-Rate: 60 ml/h, detection: OD 280 nm, 0.2/2.0 Abs-Range, Uvicord S II, chart-Speed: 0.1 mm/min, 5 ml per fraction collected.

30 Yield of F(ab')₂ preparation (Pierce)

Taking into consideration that the Fc-part represents roughly one third of the molecule, the yield of the F(ab')₂ preparation was close to 100% for both antibodies. The concentration of the sample should be 6-7 mg/ml. Purity of the F(ab')₂ preparation was monitored by SDS-PAGE.

EXAMPLE 2:PREPARATION OF BISPECIFIC ANTIBODY BAB <425,225>

Bispecific antibodies were generated by chemical recombination of IgG fragments as described by Brennan et al. (Science, 1985, 229, 81-83). The individual steps of the

5 modified procedure according to the invention are listed as follows:

F(ab')₂ product → Reduction to Fab' → Gelchromatography → Derivatization → Gelchromatography → Conjugation → Gelchromatography → Ultrafiltration → Sterile Filtration → BAbs

Both specific F(ab')₂-fragments were converted into Fab' fragments. The success of the
10 conjugation step was dependent on the selection of the appropriate Fab'-fragment for Ellman's modification. In the case of the MAb 225 / MAb 425 derived BAb the <225> component was modified. After introduction of these modifications the yield of the individual BAb's) ranged from 20-30%. Anti-225 Fab' was modified with Ellman's reagent and conjugated to the 425 specific Fab'. Bispecific antibody was recovered by
15 gelfiltration chromatography.

Details:

In this step both antibodies were reduced with DTT in order to generate Fab' fragments. The MAb 225 derived Fab' was modified with Ellman's reagent prior to conjugation. It is however possible to modify MAb 425 derived Fab' with Ellmann's reagent.

20 Fragments:

(i) F(ab' <425>)₂ 7.4 mg/ml

(ii) F(ab' <225>)₂ 6.9 mg/ml

Solution / Buffers:

PBS pH 7.4, PBS + 0.65 M NaCl + 2.5 mM EDTA, pH 7.4, 51 mM Dithiotreitol in PBS,
25 0.1 M Na-phosphate buffer, pH 8.0, 35 mM Ellman's reagent in 0.1 M Na-phosphate buffer, pH 8.0, 250 mM EDTA, pH7.4

Reagents:

1,4-Dithiotreitol, Ellman's - Reagent, sodium chloride, disodium orthophosphate, potassium dihydrogen phosphate, EDTA, Titriplex III, Superdex 200 (26/60) Pharmacia,

30 First step of synthesis:

Preparation of MAb<225>Fab'-TNB.

6550 µl F(ab')₂ MAb 225 40 mg + 65.4 µl DTT 51 mM + 65.4 µl EDTA 250 mM.

End concentration of DTT was 0.5mM and 2.5 mM for EDTA.

The reaction was overlayed with argon and incubated in water bath at 30° C for 40 min under continuously stirring. After incubation, 1120 µl of Ellman's reagent were added to the reaction mixture, this step reversibly blocks the free SH-groups in the resulting Fab'. The final concentration of Ellman's in the reaction is 5.0 mM. The reaction mixture was stirred at RT for 30 min in order to block all the SH-groups. The colour of the reaction mixture changes from clear to yellow. The reaction mixture was purified using a Superdex 200 (26/60) column with PBS + 0.65M NaCl + 2.5mM EDTA buffer, to separate the reduced Ellman's modified Fab' molecules from potential contaminants such as unreduced F(ab')₂, Fab' and surplus of reagent. The Fab-TNB fractions were pooled, overlayed with argon and stored on ice until the coupling reaction.

Second step of synthesis:

Preparation of MAb<425>Fab':

6135 µl F(ab')₂ MAb 425 40 mg + 80 µl EDTA 250 mM + 80 µl DTT 51 mM.

Start The reaction should be started not before the Fab-TNB preparation was almost finished. End concentration of reaction is 0.5 mM DTT and 2.5 mM EDTA. Reaction mixture was overlayed with argon and incubated at 30° C for 40 min. Immediately after incubation, reaction mixture was transferred to the equilibrated Superdex 200 (26/60) column, using PBS + 0.65 M NaCl + 2.5 mM EDTA pH 7.4 buffer to separate Fab' from unreduced F(ab')₂ and DTT. The buffer and collecting tube were argon saturated respectively, to prevent oxidation of the free SH groups. Fab' containing fractions were collected directly in an argon-saturated test-tube.

Third step of synthesis:

Conjugation of Fab' <425> and Fab' <225>-TNB

Coupling reaction: 32.5 ml MAb 225 Fab'-TNB; 0.9 mg/ml, 31.6 mg + 23.5 ml MAb 425 Fab' 1.5 mg/ml, 34.8 mg. The Fab' and the Fab'-TNB antibodies were combined and the volume was reduced to approx. 5ml (using argon) in an Amicon chamber containing a YM 10 membrane. The reaction mixture was overlayed with argon at 4° C overnight under continuous stirring. The conjugate was purified through a Superdex 200 (26/60) column, the buffer and column were helium-saturated. Bispecific F(ab')₂, (Peak 1) were recovered. Peak 1: purified bispecific antibody (166-187ml), Peak 2: residual Fab'. To confirm identity and purity samples were applied to a non-reducing 10% SDS-Page gel. The yield of purified BAb <425, 225> F(ab')₂ was in this typical example 11 mg (16.7%).